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(54) **Wireless communications system having a space-time architecture employing multi-element antennas at both the transmitter and receiver**

Funkkommunikationssystem mit einer Raum-Zeit-Architektur unter Verwendung von Multielementantennen sowohl beim Sender als auch beim Empfänger

Système de communication sans fil avec une architecture par couches temporelle et spatiale au moyen d'antennes à multi-éléments à émetteur ainsi qu'à récepteur

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- **FOSCHINI G J: "LAYERED SPACE-TIME ARCHITECTURE FOR WIRELESS COMMUNICATION IN A FADING ENVIRONMENT WHEN USING MULTI-ELEMENT ANTENNAS" BELL LABS TECHNICAL JOURNAL, WILEY, CA, US, vol. 1, no. 2, 21 September 1996 (1996-09-21), pages 41-59, XP000656005 ISSN: 1089-7089**

EP 0 951 091 B1

Description

Technical Field

[0001] The invention relates to a wireless communications system employing Multi-Element Antennas (MEAs) at both the transmitter and receiver.

Background of the Invention

[0002] The transmission capacity (ultimate bit rate) of a digital wireless communications system is based on a number of different parameters including (a) total radiated power at the transmitter, (b) the number of antenna elements at the transmitter and receiver, bandwidth, (c) noise power at the receiver, (d) characteristics of the propagation environment, etc. For a wireless transmission system employing an appreciable number of antennas at both the transmitter and receiver and operating in a so-called Rayleigh fading environment even without coding, the bit rate could be very large, e.g., 36 bits per second per Hz with a reasonable Signal to Noise Ratio (SNR) of 18 dB. Heretofore, it was difficult for a communications system to exchange data at a fraction of such a rate. The main reason for this is that the prior art did not appreciate the problems that had to be solved in order to build a large bit rate system.

[0003] EP-A-0 817 401 discloses decomposing an n-dimensional system into n-one dimensional systems of equal capacity when the transfer (H matrix) characteristics of the wireless channel are unknown to the transmitter. More specifically, signal components received during respective periods of time over a plurality of antennas associated with a wireless receiver are formed into respective space and time relationships in which space is associated with respective transmitter antenna elements are preprocessed, in turn, such that a collection of signal components having the same space/time relationship form a signal vector so that particular decoded signal contributions may be subtracted from the signal vector while particular undecoded contributions may be nulled out of the signal vector. The resulting vector is then supplied to a decoder for decoding to detect a primitive data stream.

[0004] EP-A-0 905 920 discloses a multiple antenna system that creates virtual sub-channels from an actual communications channel by using propagation information characterizing the actual communications channel at first and second units. For transmissions from the first unit to the second unit, the first unit sends a virtual transmitted signal over at least a subset of the virtual sub-channels using at least a portion of the propagation information. The second unit retrieves a corresponding virtual received signal from the same set of virtual sub-channels using at least another portion of said propagation information.

Summary of the Invention

[0005] We have recognized that a wireless communications system that transmits at a substantial bit rate may be achieved, in accordance with an aspect of the invention, by decomposing an m-dimensional system into m-one dimensional systems (of possibly a different capacity) when the transfer (H matrix) characteristics of the wireless channel are unknown to the transmitter. More specifically and in accordance with the principles of the invention, a burst of signal vectors is formed from different data symbols and then transmitted by a transmitter via a Multi-Element Antenna Array. The transmitted vector symbols are received as signal vectors by a plurality of different antennas associated with a wireless receiver. The symbol components of the transmitted vector symbol have an (arbitrary) order and the receiver determines the best reordering of these transmitted components and then processes the received vector to determine the reordered transmitted symbol components. Such processing starts with the lowest (e.g., first) level of the reordered components, and for each such level, cancels out interfering contributions from lower levels, if any, and nulls out interfering contributions from higher levels, if any.

[0006] Such receiver processing includes, in accordance with one embodiment of the invention, compensating the weaker of the received transmitted signal components by first removing the interference from the stronger of the received transmitted components, and then processing the result to form the bit decisions.

[0007] These and other aspects of the invention may be appreciated from the following detailed description, accompanying drawings and claims.

Brief Description of the Drawings

[0008] In the drawings:

FIG. 1 illustrates in block diagram form a wireless transmitter and receiver embodying the principles of the invention;

FIG. 2 illustrates a more detailed block diagram of the wireless receiver of FIG. 1;

FIG. 3 illustrates the reordered transmit components and corresponding decision statistics for one of the n-dimensional complex signal vectors of a received burst of κ vectors;

FIG. 4. illustrates graphically the way in which such processing is achieved to eliminate interfering signals from a signal vector being processed by the receiver of FIG. 2;

FIGs. 5 and 6 illustrate in flow chart form the program which implements such reordering in the processor 60 of FIG. 2; and

FIGs. 7 and 8 illustrate in flow chart form the processor program which processes each received vector signal to determine the corresponding transmit symbols.

Detailed Description

[0009] The following illustrative embodiment of the invention is described in the context of a point-to-point communication architecture employing a transmitter having an array of k antenna elements and a receiver having an array of n antenna elements, where, in an illustrative embodiment of the invention, $k \leq n$ and both values are > 1. For example, for transmissions at 1.9 GHz, $k \leq 16$ and $n = 16$. Moreover, as will be seen below, the bit rate/bandwidth, in terms of the number of bits/cycle, that may be achieved using the inventive architecture is indeed large.

[0010] For the sake of clarity, the detailed description assumes the following conditions. Specifically, assume that the transmitter and receiver, FIG. 1, are spaced very far apart, for example, 100λ. Also, the volume of such transmit and receive spaces is sufficient to accommodate one or more signal decorrelations. Also, locations of the transmitter and receiver may be reversed and several antennas would still be available at the receiver to receive substantially spatially decorrelated electromagnetic field samples originating from electromagnetic waves launched by the transmitter. This randomly faded matrix channel characteristic is assumed not to be known to the transmitter but may be "learned" by the receiver using certain channel measurements. Such training may be done by, for example, using m applications of standard n-fold receive diversity, one such application per transmit antenna. One example of this procedure is disclosed in the article entitled "Signal Acquisition and Tracking with Adaptive Arrays in the Digital Mobile Radio System IS-54 with Flat Fading", by J. H. Winters and published in the IEEE Transactions on Vehicular Technology, November 1993.

[0011] The following description is also discussed in the context of burst mode communications, in which temporal changes in the channel are assumed to be negligible over the duration of a burst of data, and in which the characteristics (i.e., transmission environment) of the channel may change from burst to burst. Because of this, the channel bit rate that may be achieved is treated as a random variable. Along with (m, n), a key system parameter is the spatial average Signal-to-Noise Ratio (SNR), ρ, as would be measured using a "probe" antenna element at the transmitter end and at the receiver end of the transmission volumes. The total radiated power is considered to be constrained so that if m, for example, is increased, there is proportionately less power per transmit antenna. (Note, that in a Rayleigh propagation environment, ρ is independent of the number of transmit antennas).

[0012] As mentioned above, the transmission environment of a channel is assumed to be random, and time is assumed to be discrete. Also assume the following notation:

[0013] The transmitted signal is designated as s(t) and the total power is constrained to P_o (defined below) regardless of the value of m (the dimension of s(t)). For the sake of simplicity, the following discussion assumes that the bandwidth is sufficiently narrow so that the response of the channel may be considered to be flat over the channel frequency band.

[0014] The noise signal at the receiver is designated as v(t), and is a complex n-D (Dimensional) Additive White Gaussian Noise (AWGN) process with statistically independent components of identical power N (one component for each of the n receiver antennas).

[0015] The received signal is designated as r(t), and, at a particular point in time, a received n-D signal includes one complex component per receive antenna. In the case where there is only one transmit antenna, then the transmitter radiates power P_o and the resulting (spatial) average power at the output of any of the receiving antennas is noted by P.

[0016] The spatial average SNR, ρ, at each receiver antenna is considered to be equal to P/N and independent of m in the Rayleigh propagation case.

[0017] The duration of a burst of data is κ vector symbols and is assumed to be equal to the number of intervals ("ticks") of a discrete time clock that occurs in such a burst.

[0018] A so-called matrix channel impulse response, g(t), has m columns and n rows. G(f) is used for the Fourier transform of g(t). To be consistent with the narrowband assumption, this matrix/transform is considered to be constant over the band of interest, in which notation G indicates that frequency dependence is suppressed. Thus, except for g (0), g(t) is the zero matrix. As will be seen, it may be convenient to represent the response of the matrix channel in a normalized form, h(t). Also, related to G, and for a matrix H, the equation $P^{1/2} \cdot G = P_o^{1/2} \cdot H$ defines the relationship between G and H, which provide $g(t) = (P_o/P)^{1/2} \cdot h(t)$.

[0019] Further, realizations of a form of H for an ideal Rayleigh propagation environment may be modeled so that the m x n matrix entries are the result of independent identically distributed complex Gaussian variables of unit variance.

[0020] With the foregoing in mind, and using * to designate convolution, the basic vector equation describing the channel environment affecting a transmitted signal may be represented as follows:

$$r(t)= g(t) * s(t) + v(t) \qquad (1)$$

The two vectors added on the right hand side of equation (1) are complex n-D(dimensional) vectors (i.e., 2n real dimensions). For the above narrowband assumption, equation 1 may be simplified by replacing the convolution using a matrix-vector product as follows:

$$r(t) = (P_o/(P \cdot m))^{1/2} \cdot h(t) \cdot s(t) + v(t) \qquad (2)$$

[0021] A broad block diagram illustrating a generalized version of a communication system that processes the received vector signal described by equation 2 is shown FIG. 1. In particular, source 50 supplies a m-dimensional signal to transmitter processor 100 which then transmits over selected ones of the antennas 110-1 through 110-k a m-dimensional symbol generated as a result of using m instances of a particular modulation technique, e.g., Quadrature Amplitude Modulation (QAM), in which each symbol component corresponds to a group of sequential bits. In an illustrative embodiment of the invention, the selection of m transmit antennas may be arbitrary. However, the selection could turn out to be inferior. Rather than being "stuck" with such a selection, transmitter processor 100 is arranged to systematically (or randomly) change the selection of antennas to avoid being "stuck" with an inferior selection for any appreciable amount of time. (It is noted that in one embodiment of the instant invention, a so-called feedback channel from receiver 200 to transmitter 100 is provided. The selection of transmitter antennas is then somewhat optimized based on information provided by receiver 200 to transmitter 100 via the feedback channel (represented in FIG. 1 by the dashed line.) Transmitter processor 100, more particularly, may be arranged to initially match the sequential order in which symbols are generated with the order of antennas 110-1 through 110-k, in which the first of such symbols is transmitted over antenna 110-1, the second symbol is then transmitted over antenna 110-2, and so on. If that selection turns out to be inferior based on the receiver feedback information, then transmitter processor 100 may change the selection or use a subset of the transmit antennas 110-I, all in accordance with an aspect of the invention. For example, as a result of such feedback, if the transmitter "learns" that the environment of the channel over which antennas 110-k-1 and 110-k transmit, then processor 100 may use just a subset of the antennas, e.g., 110-1 through 110-k-2, and select those antenna that may possibly result in the best reception at receiver 200 as reported via the feedback channel.)

[0022] For the system of FIG. 1, m different QAM signals may be considered to be statistically independent, but are otherwise identical modulations (although different modulations are allowable). (Note that each of the QAM modulated components of a received vector will also be referred to herein as a substream.) Also for expositional convenience, q(t) may be defined as follows:

$$q(t) \triangleq (P_o/(P \cdot m))^{1/2} \cdot s(t) \qquad (3)$$

Using equation (3), equation (2) may then be expressed simply as

$$r(t)= h(t) \cdot q(t) + v(t) \qquad (4)$$

The received vector, r(t), is used to estimate the m QAM components of the vector q(t), in which n components of the signal vector, r(t), are received by each of the receiver 200 antennas 120-1 through 120-n, respectively. The processing of the received signal to detect the transmitted symbols is the problem that receiver 200 needs to solve in accordance with the principles of the invention. The detected symbols are then mapped to respective bit sequences to reconstitute the original bit stream.

[0023] Note, that for the sake of clarity and convenience, the following discussion relating to the processing of a received vector suppresses the argument (t). Thus, for example, r(t) will be referred to simply as r, q(t) as q, etc.

[0024] Receiver 200, FIG. 2, more particularly includes, inter alia, a bank of conventional RF receiver sections (not shown) which respectively interface with antennas 120-1 through 120-n. It also includes detection processor 201, which is made up of preprocessor (also just processor) 60 and symbol processor 65, and multiplexer 70. Preprocessor 60 receives the signals as respective signal vectors from the n antennas 120-1 through 120-n, and preprocesses each received signal vector to eliminate interference between the signal components forming that vector. Such processing includes (a) subtracting interference stemming from previously detected transmitted symbols from the vector being processed, (b) nulling out of the vector being processed interference from other transmitted symbols that have not yet been processed and detected, and (c) using the stronger elements of the received signal to compensate for the weaker elements, all in accordance with the principles of the invention and as will be discussed below in detail. (Such processes are illustrated in FIG. 4 as procedures 401 through 407.) In accordance with an aspect of the invention, such compensation is achieved by determining the best reordering of the transmitted components for their detection and then processing the received vector to determine the reordered transmitted symbol components.

[0025] The reordering of the transmit components may be achieved by, for example, placing at the bottom of the vertical stack (level (1)) the detection process which will estimate the transmitted signal component that offers the largest SNR, then placing next in the vertical stack (level (2)) the detection process that will estimate the transmitted signal component having the next largest SNR of the remaining m-1 transmitted components and so on, as will be explained below in detail. (It can be appreciated from the foregoing that an alternative stacking arrangement could be readily used).

[0026] A received vector has n complex components respectively received by antennas 120-1 through 120-n. Processor 60 further processes the preprocessed signal vectors to detect the m constituent data substreams. Symbol processor 65 processes the symbols to determine the data substreams (also herein "bit decisions") respectively corresponding to the symbols. Symbol processor 65 then stores the "decision bits" in memory 61 so that the decision bits may be used to cancel interference in further processing of the received signal vector. When all of the bits in a transmitted vector have been detected, then multiplexer 70 multiplexes the bits from the various substreams to form an estimate of the original data stream outputted by source 50 (FIG. 1).

Interference Cancellation

[0027] For the following assume that receiver 200 receives a transmission burst of κ m-dimensional transmit vectors as impaired by the environment of channel 125 plus additive noise. (Note that the following discussion is given in the context of processing just one of the received vectors. It is to be understood of course that such processing/dectection equally pertains to each of the received vectors.) Each transmitted vector is received by n receiver antennas, e.g., 12 dimensional transmit vectors received via 16 antennas. Also consider that the decision statistics are to be stacked from the bottom up - i.e., as levels (1), (2), ... (m) as shown in FIG. 3, in which the vector at the first (bottom) level offers the largest SNR for the first of the transmitted components that will be detected. For such an iteration of the vector signals, assume that receiver 200 has composed the first i-1 decision statistic vectors $d^{[\cdot]}$s for the levels up to the level designated "next" in FIG. 3 and that the i-1 decisions that are based on the decision statistics for (1), (2), (i-1) are free of errors. Such decisions may be used to cancel interference stemming from the components of q that have been already determined. Note that $q_{(j)}$, j = 1, 2, ... m, denotes the reordered components of q corresponding to levels (1), (2) ...... (m). Also note that for the following discussion, it is useful to express h in terms of its m n-D columns so that (in discussing the formation of the decision statistic for detecting $q_{(i)}$) $h = [h_1\ h_2 \ldots h_m]$

[0028] Also note that the received signal, r, is the n-D vector expressed as follows:

$$r = q_1 \cdot h_1 + q_2 \cdot h_2 + q_3 \cdot h_3 \ldots + q_m \cdot h_m + v \qquad (5)$$

[0029] Note that each of the m $h_{(j)}$ may be defined using (5) as h_l (where: $1 \le l \le m$). From (5), $h_{(i)}$ is defined by the subscripted h that multiplies $q_{(i)}$ in (5). Also, r may be expressed as follows:

$$r = [q_{(1)} \cdot h_{(1)} + q_{(2)} \cdot h_{(2)} + \ldots + q_{(i-1)} \cdot h_{(i-1)}] + q_{(i)} \cdot h_{(i)} \qquad (6)$$
$$+ [q_{(i+1)} \cdot h_{(i+1)} + q_{(i+2)} \cdot h_{(i+2)} + \ldots + q_{(m)} \cdot h_{(m)}] + v$$

[0030] Note, the first bracketed sum, $[q_{(1)} \cdot h_{(1)} + q_{(2)} \cdot h_{(2)} + \ldots + q_{(i-1)} \cdot h_{(i-1)}]$, is assumed to involve only correctly detected signal components and is subtracted from r to give the n-D vector $u^{[i]}$ defined by:

$$u^{[i]} = [q_{(i)} \cdot h_{(i)}] + [q_{(i+1)} \cdot h_{(i+1)} + q_{(i+2)} \cdot h_{(i+2)} + \ldots + q_{(m)} \cdot h_{(m)}] + v \quad (7)$$

[0031] Thus, in the processing of the same received vector r that is designated "next" in FIG. 3 (i.e., stack level 8), processor 60 cancels (subtracts) from vector r the vector $[q_{(1)} \cdot h_{(1)} + q_{(2)} \cdot h_{(2)} + \ldots + q\, h_{(7)}]$ as a result of having already determined/detected the latter vector. Processor 60 then "nulls" out of the vector being processed (e.g., the level 8 vector), the interference from transmitted signal components that have not yet been detected, i.e., the interference stemming from the transmission of $q_{(9)}$ through $q_{(12)}$, as shown in FIG. 3.

Interference Nulling Using Spatial Matched Filters

[0032] For those components (i+1) (i+2), ... (m) of q that have not yet been determined/detected, $u^{[i]}$ may be projected orthogonal to the m-i dimensional space spanned by $h_{(i+1)}, h_{(i+2)}, \ldots h_{(m)}$. The result of that projection is noted herein as $v^{[i]}$. The "interference nulling step"*, in a sense "frees" the detection process for $q_{(i)}$ of interference stemming from the simultaneous transmission of $q_{(i+1)}, q_{(i+2)}, \ldots q_{(m)}$.
The direction and magnitude of the spatial-matched-filter vector $d^{[i]}$ is considered next. Note that $q_{(i)}$ multiplies each component of $v^{[i]}$ so that the vector $v^{[i]}$ is similar to the situation of receiving an [n-(i-1)]-fold diversity interference-free signal in vector AWGN. Explicitly, the decision statistic for $q_{(i)}$ is the scalar product $< v^{[i]}, d^{[i]} >$, in which the noise power of the scalar product is proportional to $\|d^{[i]}\|^2$. A standard result about optimum receive diversity may be used to represent the optimized signal to noise ratio, $SNR_{(i)}$. The resulting decision statistic also has the signal power that is proportional to $\|d^{[i]}\|^2$. It is thus convenient to define $\underline{v}^{[i]}$ to denote the vector $v^{[i]}$ in the hypothetical situation where space 125, FIG. 1, is free of additive noise. The $SNR_{(i)}$ of that medium is optimized when $d^{[i]}$ is any multiple of the value $\underline{v}^{[i]}$, as would follow by applying the well-known Cauchy-Schwarz inequality to the signal power term in the numerator in an expression for SNR. Indeed, the best of all of the opportunities for spatial filtering, is when the vector used in a scalar product to collapse $v^{[i]}$ to a scalar decision statistic is in the direction of $\underline{v}^{[i]}$: The reason for this is that when the collapsing vector is proportional to $\underline{v}^{[i]}$, the Cauchy-Schwarz upper bound on SNR is achieved with equality. Note that $\|\underline{v}^{[i]}\|^2$appears multiplicatively in both numerator and the denominator of the optimum SNR, therefore, the optimum SNR is invariant with respect to the $\|\underline{v}^{[i]}\|$. While $d^{[i]}$ has the direction of $\underline{v}^{[i]}$ the scale of $d^{[i]}$ is simply set in accordance with the (arbitrary) scale factor used for the decision regions employed in the final stage of QAM detection. (Note that the processes of canceling, nulling and compensating is shown graphically in FIG. 4, as mentioned above.)
· In the asymptote of high SNR the incremental advantage of not nulling, but instead maximizing the signal to noise plus self-interference is negligible.

Compensation

[0033] Processor 60 upon receiving a burst of signal vectors stores the signal vectors in memory 61. As is done conventionally, the burst may contain information which receiver 200 may use to "learn" the transmission characteristics of the transmission environment 125 (FIG. 1). Such conventional learning (or training) information may be positioned at, for example, either the beginning (preamble) or mid point (midamble) of a burst of signal vectors, as is well-known.
[0034] After storing the received training vectors in memory, processor 60 then determines the stacking order in which the transmitted data symbols should be detected as a function of their respective SNRs. This is done to minimize the probability of making a detection error in the processing of a burst of received vectors. The determination includes forming spatially-matched-filter vectors by iteratively determining the order in which the transmitted symbols in a vector symbol are detected from a received vector. Note that the goal of such re-ordering is to maximize the minimum signal-to-noise ratio of the detection process. Processor 60, more specifically, stacks the m decision statistics for the m components in accordance with the following criterion:

$$\text{maximize minimum } [SNR_{(i)}, 1 \leq i \leq m] \quad (8).$$

The reason that this criterion corresponds to minimizing the probability of a burst error is that in a high SNR situation (i.e., high p situation) the probability that a burst contains at least one error could be dominated by the $q_{(i)}$ that has the least $SNR_{(i)}$ (as will be shown below in connection with equations (10) and (11).
[0035] Processor builds the stack using a so-called "myopic" optimization procedure, which turns out to be the global

optimization procedure expressed by equation (8) -- meaning that processor 60 starts at the bottom level of the stack and proceeds iteratively up to the m-th level, always choosing the next decision statistic among the options that maximizes the SNR for that level. With myopic optimization, processor 60 need only consider $\sim m^2/2$ options in filling the totality of all m stack levels as opposed to a thorough evaluation of m! stacking options.

[0036] (As an aside, note that the improved compensation feature may be achieved using an improved iterative solution that is somewhat more computational. Specifically, assume that processor 60 is proceeding next to the i-th stack level. Once it makes the i-th decision, assume that no error was made. For that case, then, processor 60 may subtract the complex number corresponding to the constellation point from the decision statistic. This process provides processor 60 with the value of the noise that was included in the i-th decision statistic. This noise is correlated with corresponding additive noises of decision statistics further up the stack. Consequently, each additive noise term in subsequent decision statistics can be adjusted by subtracting off the conditional expectation of that noise conditioned on all the contributions of the assumed known additive noises of decision statistics lower in the stack.)

[0037] The program which implements the above described vertical ordering/layering in the processor 60 of FIG. 2 is shown in flow chart form in FIGs. 5 and 6. Specifically, FIG. 5 illustrates the way in which the optimum decision statistic vector $d^{[i]}$ for each of m stack levels, i = 1, 2, 3,..... m is determined. When the program is entered at block 500, following the storage of a received burst of signal vectors and the processing of the training information, the program proceeds to block 501 where it sets a variable i to a value of one and then proceeds to block 502. Processor 60, at block 502, processes the generic signal vectors to identify the spatial-matched-filter vector having the largest SNR of all of the candidates (as discussed above and as will be further discussed below). When processor 60 identifies that vector, it then (block 503) scales the vector relative to a respective scaling value. Processor 60 then stores the scaled vector in memory 61. Processor 60 then exits (blocks 505 and 506) if it determines that it has completed the forming and ordering (stacking) of all of the spatially-matched-filter vectors (i.e., i = m). If it has not completed the forming and ordering process, then processor 60 (blocks 505 and 507) increments i and returns to block 502 to find which of the remaining candidates offers the largest SNR and places that candidate next in the stack.

[0038] An expanded view of block 502 is shown in FIG. 6. In particular, assume that processor 60 has already stored the channel matrix in memory 61. Also assume that processor 60 has already stacked in the preferred order i-1 the matching vector candidates and that processor 60 is now forming the remaining (m - (i - 1)) candidate vectors to determine which one of those candidates will be inserted at the ith level of the stack. At block 601, processor 60 forms a generic linear combination of the i-1 vectors positioned at the lower levels in the stack (and which have already been ordered in the stack), containing interferers. Processor 60 subtracts (block 603) that combination from the generic noise-free vector read (block 602) from memory 61, thereby leaving a representation of the vector for the transmitted signal components that have not yet been detected. Processor 60 then (block 608) initializes a variable j to a value of one to ensure that it will process all of the vector signals. For each vector candidate, e.g., the ith candidate vector, processor 60 (block 605) projects that vector orthogonally away from the (m- (i-1)) vector signals that interfere with the ith candidate vector to eliminate those interferers from the decision process. The resulting vector should be a vector that is free of interference from the other ones of the received vector signals. Processor 60 then (block 607) measures the norm (corresponding to the square of the length of the vector with respect to an origin in which each of the n components equals zero) to determine the value for that norm. The value of the norm is proportional to the SNR for that decision statistic. Processor 60 then determines whether the SNR is the best (largest) SNR for all of the candidates processed thus far. If it is, then processor 60 stores (block 609) the spatially-matched-filter vector having that SNR and its associated norm in the ith level of the stack and then proceeds to block 608 to continue the processing of the remaining candidates. If it is not, then processor 60 goes directly to block 608. After storing the selected signal vector candidate and its norm in memory, processor 60 then checks to see if it is done. If not, processor 60 increments j and proceeds to block 605, otherwise, it proceeds to block 503, FIG. 5.

[0039] Accordingly, then, processor 60 operating under control of the foregoing program places, for detection, the transmitted signal components in an optimum order based on their respective SNRs. As discussed above, processor 60 then uses each of the stacked spatially-matched-filter vectors to determine a bit combination/decision that a processed symbol most likely represents. As mentioned above, the procedure for determining a symbol is illustrated in FIG. 4, and a discussion of that procedure is repeated, but in the context of FIGs. 7 and 8.

[0040] Specifically, the program which implements in processor 60 (and somewhat in processor 65) the above nulling, canceling and matching steps 401, 402 and 403 illustrated in FIG. 4 is shown in flow chart form in FIGs. 7 and 8. Starting with FIG. 7, processor 60 begins such processing by entering the program of FIG. 7 at block 700. At that point, processor 60, initializes (block 701) a variable i to a value of 1 and uses i to point to a respective level in the stack. For the following discussion, assume that processor 60 is processing the ith level in the stack. Processor 60 (block 702) processes the vector signal (as shown for procedures 401, 402 and 403, FIG. 4) positioned at the ith level in the stack to determine the symbol $q_{(i)}$ most likely represented by the signal vector. Processor 60 stores the bit decisions corresponding to $q_{(i)}$ in memory 61, and then checks (block 703) the value of i to see if it has completed m successive processings of the received vector signal r. If so, then processor 60 exits the program. Otherwise, processor 60 (block 705) increments i

to point to the next succeeding level in the stack and proceeds to block 702 to process the received signal vector in a manner corresponding to that level.

[0041] An expanded version of block 702 is shown in FIG. 8. Specifically, at block 801 processor 60 reads from memory 61 the received n-dimensional vector signal r(t), and then reads (block 802) from memory 61 those signal vector components that have already been processed/detected in accordance with block 702, i.e., those components below the ith level in the stack. Then, in the manner discussed above, processor 60 cancels the i-1 retrieved signal vectors, $q_{(1)} \cdot h_{(1)}$, $q_{(2)} \cdot h_{(2)}, \ldots, q_{(i-1)} \cdot h_{(i-1)}$, out of r and then proceeds to block 803 with a signal vector substantially devoid of interference from those i-1 vectors. Processor 60 then projects the resulting vector away from the interferers that have not yet been detected. That is, processor 60 reads from memory the spatial match vector $d^{[i]}$ determined at block 504 for the ith level of the stack. Processor 60 (cooperating with processor 65) then takes the scalar product of the spatial match vector and the result generated at block 803 to generate a complex number.

[0042] Processor 65 (805) then determines which one of a conventional multipoint signal constellation, e.g., a sixteen point signal constellation (as shown for constellation 404, FIG. 4), is closest to the complex number. An example of such a point is shown in FIG. 4 in which point 405 representing the complex number is closest to the constellation point of quadrant 406. Processor 65 (block 806) then stores the data bit decisions represented by the identified constellation point in memory and then returns control to processor 60. Processor 60 then proceeds to block 703 to process the next level in the stack.

[0043] When the received signal vector has been so processed and all symbols detected, with the corresponding bits decisions stored in memory, then multiplexer 70 multiplexes the bit decisions to an output terminal.

[0044] The advantages of the foregoing may be appreciated by way of an example based on a particular set of parameters, in which, for example; $p = 18$ dB, and (m,16) with $m \leq 16$, and in which transmitter 100 and receiver 200 (FIG. 1) may have antenna arrays of up to 16 antennas. Also, assume that 95% of the transmission bursts are free of errors (i.e., at most a 5% outage), and an ideal Rayleigh propagation environment for space 125. Further assume that each burst contains, besides training vectors, 100 vector symbols. For the assumed parameters and 16 x 16 system, the Shannon capacity is 79.1 bps/Hz. (Note that "Shannon capacity" is a well-known term in the art.)

[0045] The number of transmit antennas, m, and the number of points in each of the planar constellations, K, may be optimized to maximize the number of bps/Hz. The number of constellation points in m-D (or n-D) complex space may be expressed as follows:

$$\text{Number of constellation points} = [\text{Number of 2-D constellation points}]^{[\text{Number of substreams}]} = K^m \qquad (9)$$

The optimization process involves performing the following procedure to iteratively explore m = 1, 2, 3, ... 16. For each of these cases, as many bits per 2-D constellation may be used, to the point where one more bit would violate the so-called 5% "outage constraint"[1].

[1] When the number of constellation points was greater than two and not a perfect square we used a regular constellation with good distance properties. For example, for an 8 point constellation we used a square with four equilateral triangles attached to the four sides and pointing outward. The vertices of the square, along with the four triangle vertices that oppose each of the four sides of the square, made up the constellation.

The equation for the probability of at least one error in a block with K vector symbols is shown below as equation (10). Evaluation of this probability requires that the $SNR_{(i)}$ for $1 \leq i \leq m$. Monte-Carlo generated H realizations may be used to get samples of the m SNRs. For K point QAM constellations the formula in the large ρ realm is

$$\text{Prob[Erroneous Block]} \approx \kappa \times \sum_{i=1}^{m} P_b\left(SNR_{(i)}\right) \qquad (10)$$

where $P_b(.)$ is the well known function for the probability of bit error of a 2-D constellation as a function of SNR, namely:

$$P_b(SNR_{\theta}) \approx [(K^{½} - 1)/(K^{½} \cdot \log_2 K)] \times p^{-½} \cdot \int_a^{\infty} \exp(-x^2)\, dx \quad (11)$$

where

$$a = [(3 \cdot SNR_{\theta})/(2 \cdot (K - 1))]^{½}.$$

[0046] Using equations (9) and (10), and starting with m = 1 the system of FIG. 1 may support K = 128 point constellations or equivalently 7 bps/Hz. For m = 2 the system can support a 32 point planar constellation of 5 bps/Hz. For m = 7, the system can support 16 point constellations of 4 bps/Hz. For m = 12, the system can support 3 bps/Hz, which is one of the higher dimensional constellations of 8^{12} = 68,719,476,736 points or 36 bps/Hz.

[0047] The foregoing is merely illustrative of the principles of the invention. Those skilled in the art will be able to devise numerous arrangements, which, although not explicitly shown or described herein, nevertheless embody those principles that are within the scope of the invention. For example, instead of maintaining a constant BER and outage probability, the skilled artisan could maintain a constant transmitted power, and express the relative merit of the two approaches in terms of a difference in outage probability as a function of rate. As another example, the skilled artisan could hold the BER and outage probability constant for both systems, and express the relative merit in terms of transmitter power, or, the life of a battery in a portable system.

[0048] In addition, those skilled in the prior art would recognize from the foregoing that the notion of using more transmit antennas than transmit radios at the transmitter and selecting a subset of antennas on which to transmit, could be similarly applied to the receiver. In that case, more receive antennas would be deployed than receive radios and a subset of the receive antennas on which to receive a transmitted vector signal would be selected.

[0049] Those skilled in the relevant art would also recognize from the foregoing that in certain applications of the claimed invention it may be desirable to use only a subset of the inventive features. For example, it may be desirable to use just nulling but not cancellation and reordering, or else nulling and cancellation but not ordering.

Claims

1. A communications system comprising a transmitter (100) having k antennas (110) and a receiver (200) having n antennas (120) for receiving signals from said transmitter (100) as n-dimensional received signal vectors, where n ≥ k, each of said received signal vectors comprising a linear combination of symbols from said transmitter (100) and additive noise, said communications system being **CHARACTERIZED in that**
   said transmitter (100) is responsive to receipt of an m-dimensional transmit symbol vector from a source (50), components of said transmit symbol vector comprising Quadrature Amplitude Modulation i.e. QAM symbols, said transmit symbol vector being transmitted over m of the k antennas (110) using a predetermined modulation technique, where k ≥ m > 1, and
   wherein said receiver (200) is further **CHARACTERIZED by**
   a detection processor (201) that processes the n-dimensional received signal vector to form an estimate of the m-dimensional transmit symbol vector, the detection processor (201) further comprising
   a processor (60) for a) determining a preferred permutation of integers 1, 2, ... m, which define an order in which said m components of said transmit symbol vector are estimated, and in which the preferred permutation is a function of the signal-to-noise ratios of the m components, and b) for then estimating, in the order defined by said preferred permutation, the i-th ordered component of the transmit symbol vector by nulling out from the received signal vector contributions due to transmit symbol vector components i+1, i+2, ... m which have not yet been estimated, and canceling out from the received signal vector contributions due to transmit symbol vector components. 1, 2, ... i-1 which have already been estimated, where i denotes the i-th element of the preferred permutation.

2. The communications system of claim 1 wherein signals received by said receiver are, at least in part, training signals, and wherein the detection processor (201) is arranged to repeatedly process the received training signals characterizing the signal propagation environment to generate a set of m spatially matched filter vectors, offering the best Signal-to-Noise Ratio (SNR) for detecting the m transmitted symbols.

3. The communications system of claim 1 wherein the order for detecting the m transmitted symbols maximizes the

minimum of the m signal-to-noise ratios of the detection process.

4. The communications system of claim 1 wherein the selection of the transmitter antennas (110) is randomly changed prior to the transmission of a group of transmit vector symbols.

5. The communications system of claim 1 further comprising a feedback channel from the receiver to the transmitter and wherein the selection of the transmitter antennas (110) is optimized based on signal propagation environment information that the receiver (200) supplies to the transmitter (100) via the feedback channel.

6. The communications system of claim 1 further comprising a feedback channel from the receiver (200) to the transmitter (100) and wherein the transmitter (100) transmits substreams of a demultiplexed stream of symbols supplied by a source (50) over respective ones of a predetermined set of transmit antennas (110) and changes the selection of antennas forming the set of antennas based on signal propagation environment information supplied by the receiver (200) via the feedback channel.

7. The communications system of claim 1 further comprising a feedback channel from the receiver (200) to the transmitter (100) and wherein the transmitter (100) transmits a vector symbol over a subset of the k transmitter antennas (110), in which the subset is selected based on signal propagation environment information supplied by the receiver (200) via a feedback channel.

8. The communications system of claim 1 wherein the receiver (200) has an arbitrary number of receive antennas (120) greater than n and wherein the n antennas that are used to receive signals from said transmitter (100) as n-dimensional received signal vectors is a subset of the arbitrary number of receive antennas (120).

9. The communications system of claim 1 wherein the rate at which symbols may be received accurately at the receiver (200) is proportional to the number of transmit antennas (110) used to transmit the symbols and logarithmic in the level of transmitted power so that the level of power at which symbols may be transmitted at the transmitter (100) may be substantially decreased by increasing the number of transmit antennas (110) by a relatively small number.

10. A wireless transmitter for a communications system as claimed in any of the claims 1-9 comprising
a source (50) of a stream of symbols,
a plurality of transmitter antennas (110), and **CHARACTERIZED BY**
a transmitter processor (100) which demultiplexes the symbol stream into m substreams of symbols and which then transmits each substream of symbols over a selected one of the transmitter antennas (110) using a predetermined modulation technique.

11. The transmitter of claim 10 wherein said plurality of transmitter antennas (110) is greater than m antennas, where m > 1, and wherein selection of the m transmitter antennas (110) used to transmit the m substreams of symbols is arbitrary.

12. The transmitter of claim 10 wherein the selection of the transmitter antennas (110) is randomly changed prior to the transmission of a group of symbols.

13. The transmitter of claim 10 further comprising a feedback channel from a receiver of the transmitted symbols to the transmitter and wherein the transmitter transmits a vector symbol over a subset of the plurality of transmitter antennas (110), in which the subset is selected based on signal propagation environment information received from the receiver (200) via the feedback channel.

14. A wireless receiver for a communications system as claimed in any of the claims 1-9 comprising
a plurality of receiver antennas (120) for respectively receiving a plurality of n signal components forming a received signal vector, where n > 1, and
CHARACTERIZED BY
a processor (60) that stores a received signal vector in memory (61) with other received signal vectors forming a burst of signal vectors, and
a detection processor (201) which processes the stored received signal vector to determine components of a transmitted signal vector in an order determined as a function of respective signal-to-noise ratios determined for particular decision statistics so that a) interference stemming from transmitted symbol vector components that have been processed are canceled out of a signal vector that is currently being processed, b) interference stemming from

transmitted symbol vector components that have not yet been processed is nulled out of the signal vector that is currently being processed by projecting the signal vector orthogonal to a space occupied by the latter interference, and then processing the projected signal vector in accordance with a predetermined demodulation technique to identify the components of the transmitted symbol vector.

15. The receiver of claim 14 wherein the detection processor (201) includes repeatedly processing data characterizing the transmission environment to generate a set of m spatially matched filter vectors offering the best Signal-to-Noise Ratio (SNR) for detecting the components of the transmitted symbol vector.

16. The receiver of claim 14 wherein the order for detecting the components of the transmitted symbol vector is to maximize the minimum signal-to-noise ratio of the detection process.

Patentansprüche

1. Kommunikationssystem, umfassend einen Sender (100) mit k Antennen (110) und einen Empfänger (200) mit n Antennen (120), um Signale von diesem Sender (100) als n-dimensionale Empfangssignalvektoren zu empfangen, wobei $n \geq k$, wobei jeder dieser Empfangssignalvektoren eine lineare Kombination von Symbolen vom Sender (100) und additives Rauschen einschließt, wobei dieses Kommunikationssystem **dadurch gekennzeichnet ist, dass** der Sender (100) auf den Empfang eines m-dimensionalen Sendesymbolvektors von einer Quelle (50) anspricht, wobei Komponenten des Sendesymbolvektors Quadratur-Amplitudenmodulationssymbole, d. h. QAM-Symbole, umfassen, der Sendesymbolvektor mithilfe einer vorbestimmten Modulationstechnik über m der k Antennen (110) gesendet wird, wobei $k \geq m > 1$, und
wobei der Empfänger (200) außerdem **gekennzeichnet ist durch** einen Erkennungsprozessor (201), der den n-dimensionalen Empfangssignalvektor verarbeitet, um eine Schätzung des m-dimensionalen Sendesymbolvektors zu formen, wobei der Erkennungsprozessor (201) außerdem umfasst einen Prozessor (60), um a) eine bevorzugte Permutation von Ganzzahlen 1, 2, ..., m zu bestimmen, die eine Reihenfolge definieren, in der die m Komponenten des Sendesymbolvektors geschätzt werden, und wobei die bevorzugte Permutation eine Funktion der Signal-Rausch-Verhältnisse der m Komponenten ist, und b) um dann in der Reihenfolge, die durch diese bevorzugte Permutation definiert wird, die i.te Komponente des Sendesymbolvektors zu bestimmen, indem die Beiträge, die auf Sendesymbolvektorkomponenten i+1, i+2, ..., m zurückzuführen sind, die noch nicht geschätzt wurden, aus dem Empfangssignalvektor ausgenullt werden, und Beiträge, die auf Sendesymbolvektorkomponenten 1, 2, ..., i-1 zurückzuführen sind, die bereits geschäzt wurden, aus dem Empfangssignalvektor gelöscht werden, wobei i das i.te Element der bevorzugten Permutation bezeichnet.

2. Kommunikationssystem nach Anspruch 1, wobei die Signale, die vom Empfänger empfangen werden, mindestens zum Teil Trainingsignale sind, und wobei der Erkennungsprozessor (201) angeordnet ist, um die empfangenen Trainingsignale, die die Signalausbreitungsumgebung kennzeichnen, wiederholt zu verarbeiten, um einen Satz von m räumlich angepassten Filtervektoren zu erzeugen, die das beste Signal-Rausch-Verhältnis (SNR) zur Erkennung der m Sendesymbole bieten.

3. Kommunikationssystem nach Anspruch 1, wobei die Reihenfolge zur Erkennung der m Sendesymbole das Minimum der m Signal-Rausch-Verhältnisse des Erkennungsprozesses maximiert.

4. Kommunikationssystem nach Anspruch 1, wobei die Wahl der Sendeantennen (110) vor dem Senden einer Gruppe von Sendevektorsymbolen zufällig geändert wird.

5. Kommunikationssystem nach Anspruch 1, außerdem umfassend einen Rückkopplungskanal vom Empfänger zum Sender, und wobei die Wahl der Sendeantennen (110) auf der Basis von Signalausbreitungsumgebungsinformation optimiert wird, die vom Empfänger (200) über den Rückkopplungskanal dem Sender (100) zugeführt wird.

6. Kommunikationssystem nach Anspruch 1, außerdem umfassend einen Rückkopplungskanal vom Empfänger (200) zum Sender (100), und wobei der Sender (100) Nebenströme eines demultiplexierten Stroms von Symbolen, die von einer Quelle (50) zugeführt werden, über jeweilige aus einem vorbestimmten Satz von Sendeantennen (110) sendet, und die Auswahl von Antennen, die den Antennensatz bilden, auf der Basis der Signalausbreitungsumgebungsinformation ändert, die vom Empfänger (200) über den Rückkopplungskanal zugeführt wird.

7. Kommunikationssystem nach Anspruch 1, außerdem umfassend einen Rückkopplungskanal vom Empfänger (200)

zum Sender (100), und wobei der Sender (100) ein Vektorsymbol über eine Teilmenge der k Sendeantennen (110) sendet, wobei die Teilmenge auf der Basis der Signalausbreitungsumgebungsinformation gewählt wird, die vom Empfänger (200) über einen Rückkopplungskanal zugeführt wird.

8. Kommunikationssystem nach Anspruch 1, wobei der Empfänger (200) eine beliebige Zahl von Empfangsantennen (120) aufweist, die größer als n ist, und wobei die n Antennen, die benutzt werden, um Signale vom Sender (100) als n-dimensionale Empfangssignalvektoren zu empfangen, eine Teilmenge der beliebigen Zahl von Empfangsantennen (120) sind.

9. Kommunikationssystem nach Anspruch 1, wobei die Geschwindigkeit, mit der Symbole am Empfänger (200) richtig empfangen werden können, proportional zur Zahl der Sendeantennen (110), die zum Senden der Symbole benutzt werden, und logarithmisch zum Sendeleistungspegel ist, sodass der Leistungspegel, bei dem Symbole am Sender (100) gesendet werden können, wesentlich verringert werden kann, indem die Zahl der Sendeantennen (110) um eine relativ kleine Zahl erhöht wird.

10. Funksender für ein Kommunikationssystem nach einem der Ansprüche 1 - 9, umfassend
eine Quelle (50) eines Symbolstroms,
eine Vielzahl von Sendeantennen (110), und **gekennzeichnet durch**
einen Sendeprozessor (100), der den Symbolstrom zu m Symbolnebenströmen demultiplexiert und dann jeden Symbolnebenstrom mithilfe einer vorbestimmten Modulationstechnik über eine gewählte der Sendeantennen (110) sendet.

11. Sender nach Anspruch 10, wobei die Vielzahl von Sendeantennen (110) größer ist als m Antennen, wobei $m > 1$, und wobei die Wahl der m Sendeantennen (110), die zum Senden der m Symbolnebenströme benutzt werden, beliebig ist.

12. Sender nach Anspruch 10, wobei die Wahl der Sendeantennen (110) vor der Übertragung einer Symbolgruppe zufällig geändert wird.

13. Sender nach Anspruch 10, außerdem umfassend einen Rückkopplungskanal von einem Empfänger der gesendeten Symbole zum Sender, und wobei der Sender ein Vektorsymbol über eine Teilmenge der Vielzahl von Sendeantennen (110) sendet, wobei die Teilmenge auf der Basis der Signalausbreitungsumgebungsinformation gewählt wird, die vom Empfänger (200) über den Rückkopplungskanal empfangen wird.

14. Funkempfänger für ein Kommunikationssystem nach einem der Ansprüche 1 - 9, umfassend
eine Vielzahl von Empfangsantennen (120), um jeweils eine Vielzahl von n Signalkomponenten zu empfangen, die einen Empfangssignalvektor formen, wobei $n > 1$, und **gekennzeichnet durch**
einen Prozessor (60), der einen Empfangssignalvektor mit anderen Empfangssignalvektoren, die einen Burst von Signalvektoren formen, in einem Speicher (61) speichert, und
einen Erkennungsprozessor (201), der die gespeicherten Empfangssignalvektoren verarbeitet, um Komponenten eines Sendesignalvektors in einer Reihenfolge zu bestimmen, die als eine Funktion jeweiliger Signal-Rausch-Verhältnisse bestimmt wurden, die für besondere Entscheidungsstatistiken bestimmt wurden, sodass a) Interferenzen, die von Sendesymbolvektorkomponenten stammen, die bereits verarbeitet wurden, aus einem gerade verarbeiteten Signalvektor gelöscht werden, b) Interferenzen, die von Sendesymbolvektorkomponenten stammen, die noch nicht verarbeitet wurden, aus dem gerade verarbeiteten Signalvektor ausgenullt werden, indem der Signalvektor orthogonal zu einem Raum projiziert wird, der von der letzteren Interferenz eingenommen wurde, und der projizierte Signalvektor dann einer vorbestimmten Demodulationstechnik entsprechend verarbeitet wird, um die Komponenten des Sendesymbolvektors zu identifizieren.

15. Empfänger nach Anspruch 14, wobei der Erkennungsprozessor (201) das wiederholte Verarbeiten von Daten einschließt, die die Übertragungsumgebung kennzeichnen, um einen Satz von m räumlich angepassten Filtervektoren zu erzeugen, die das beste Signal-Rausch-Verhältnis (SNR) zur Erkennung der Komponenten des Sendesymbolvektors bieten.

16. Empfänger nach Anspruch 14, wobei die Reihenfolge der Erkennung der Komponenten des Sendesymbolvektors darin besteht, das minimale Signal-Rausch-Verhältnis des Erkennungsprozesses zu maximieren.

Revendications

1. Système de communications comprenant un émetteur (100) ayant k antennes (110) et un récepteur (200) ayant n antennes (120) pour recevoir des signaux dudit émetteur (100) sous forme de vecteurs de signaux reçus de n dimensions, où $n \geq k$, chacun desdits vecteurs de signaux reçus comprenant une combinaison linéaire de symboles provenant dudit émetteur (100) et de bruit additif, ledit système de communications étant **CARACTERISE** en ce que ledit émetteur (100) est sensible à la réception d'un vecteur de symbole émis de m dimensions depuis une source (50), des composantes dudit vecteur de symbole émis comprenant des symboles de Modulation d'Amplitude en Quadrature, c.-à-d. QAM,, ledit vecteur de symbole émis étant émis sur m des k antennes (110) au moyen d'une technique de modulation prédéterminée, où $k \geq m > 1$, et
dans lequel ledit récepteur (200) est en outre **CARACTERISE par**
un processeur de détection (201) qui traite le vecteur de signal reçu de n dimensions afin de former une estimation du vecteur de symbole émis de m dimensions, le processeur de détection (201) comprenant en outre
un processeur (60) pour a) déterminer une permutation préférée de nombres entiers 1, 2, ..., m, qui définissent un ordre dans lequel lesdites m composantes dudit vecteur de symbole émis sont estimées, et dans lequel la permutation préférée est fonction des rapports signal/bruit des m composantes, et b) estimer ensuite, dans l'ordre défini par ladite permutation préférée, la composante de l' $i^{ème}$ ordre du vecteur de symbole émis en annulant du vecteur de signal reçu les contributions dues aux composantes de vecteur de symbole émis i+1, i+2, ..., m, qui n'ont pas encore été estimées, et en annulant du vecteur de signal reçu les contributions dues aux composantes de vecteur de symbole émis 1, 2, ..., i-1, qui ont déjà été estimées, où i désigne l' $i^{ème}$ élément de la permutation préférée.

2. Système de communications selon la revendication 1, dans lequel les signaux reçus par ledit récepteur sont, au moins en partie, des signaux d'apprentissage, et dans lequel le processeur de détection (201) est agencé pour traiter répétitivement les signaux d'apprentissage reçus caractérisant l'environnement de propagation des signaux afin de générer un ensemble de m vecteurs de filtres adaptés spatialement, offrant le meilleur Rapport Signal/Bruit (SNR) pour détecter les m symboles émis.

3. Système de communications selon la revendication 1, dans lequel l'ordre de détection des m symboles émis maximise le minimum des m rapports signal/bruit du processus de détection.

4. Système de communications selon la revendication 1, dans lequel la sélection des antennes d'émetteur (110) est changée de façon aléatoire avant l'émission d'un groupe de symboles de vecteur émis.

5. Système de communications selon la revendication 1, comprenant en outre un canal de contre-réaction depuis le récepteur vers l'émetteur et dans lequel la sélection des antennes d'émetteur (110) est optimisée d'après les informations d'environnement de propagation des signaux que le récepteur (200) fournit à l'émetteur (100) par l'intermédiaire du canal de contre-réaction.

6. Système de communications selon la revendication 1, comprenant en outre un canal de contre-réaction depuis le récepteur (200) vers l'émetteur (100) et dans lequel l'émetteur (100) transmet des sous-trains d'un train démultiplexé de symboles fourni par une source (50) sur des antennes respectives d'un ensemble prédéterminé d'antennes d'émission (110) et change la sélection d'antennes formant l'ensemble d'antennes d'après les informations d'environnement de propagation des signaux fournies par le récepteur (200) par l'intermédiaire du canal de contre-réaction.

7. Système de communications selon la revendication 1, comprenant en outre un canal de contre-réaction depuis le récepteur (200) vers l'émetteur (100) et dans lequel l'émetteur (100) émet un symbole de vecteur sur un sous-ensemble des k antennes d'émetteur (110), dans lequel le sous-ensemble est sélectionné d'après les informations d'environnement de propagation des signaux fournies par le récepteur (200) par l'intermédiaire d'un canal de contre-réaction.

8. Système de communications selon la revendication 1, dans lequel le récepteur (200) a un nombre arbitraire d'antennes de réception (120) supérieur à n et dans lequel les n antennes qui sont utilisées pour recevoir des signaux dudit émetteur (100) sous forme de vecteurs de signaux reçus de n dimensions constituent un sous-ensemble du nombre arbitraire d'antennes de réception (120).

9. Système de communications selon la revendication 1, dans lequel le débit auquel les symboles peuvent être reçus avec précision au niveau du récepteur (200) est proportionnel au nombre d'antennes d'émission (110) utilisées pour transmettre les symboles et logarithmique en niveau de puissance émise si bien que le niveau de puissance auquel

les symboles peuvent être émis au niveau de l'émetteur (100) peut être sensiblement diminué en augmentant le nombre d'antennes d'émission (110) par un nombre relativement petit.

10. Emetteur sans fil pour un système de communications selon l'une quelconque des revendications 1 à 9, comprenant une source (50) d'un train de symboles, une pluralité d'antennes d'émetteur (110), et **CARACTERISE PAR** un processeur d'émetteur (100) qui démultiplexe le train de symboles en m sous-trains de symboles et qui émet ensuite chaque sous-train de symboles sur une antenne sélectionnée des antennes d'émetteur (110) au moyen d'une technique de modulation prédéterminée.

11. Emetteur selon la revendication 10, dans lequel ladite pluralité d'antennes d'émetteur (110) est supérieure à m antennes, où m > 1, et dans lequel la sélection des m antennes d'émetteur (110) utilisées pour émettre les m sous-trains de symboles est arbitraire.

12. Emetteur selon la revendication 10, dans lequel la sélection des antennes d'émetteur (110) est changée de façon aléatoire avant l'émission d'un groupe de symboles.

13. Emetteur selon la revendication 10, comprenant en outre un canal de contre-réaction depuis un récepteur des symboles émis vers l'émetteur et dans lequel l'émetteur émet un symbole de vecteur sur un sous-ensemble de la pluralité d'antennes d'émetteur (110), dans lequel le sous-ensemble est sélectionné d'après des informations d'environnement de propagation des signaux reçues du récepteur (200) par l'intermédiaire du canal de contre-réaction.

14. Récepteur sans fil pour un système de communications selon l'une quelconque des revendications 1 à 9, comprenant une pluralité d'antennes de récepteur (120) pour respectivement recevoir une pluralité de n composantes de signal formant un vecteur de signal reçu, où n > 1, et **CARACTERISE PAR** un processeur (60) qui mémorise un vecteur de signal reçu dans une mémoire (61) avec d'autres vecteurs de signaux reçus formant une rafale de vecteurs de signaux, et un processeur de détection (201) qui traite le vecteur de signal reçu mémorisé afin de déterminer des composantes d'un vecteur de signal émis dans un ordre déterminé en fonction de rapports signal/bruit respectifs déterminés pour des statistiques de décision particulières de telle sorte que a) le brouillage généré par les composantes de vecteur de symbole émis qui ont été traitées soit supprimé d'un vecteur de signal en cours de traitement, b) le brouillage généré par les composantes de vecteur de symbole émis qui n'ont pas encore été traitées soit supprimé du vecteur de signal en cours de traitement en projetant le vecteur de signal orthogonal à un espace occupé par ce brouillage, puis en traitant le vecteur de signal projeté conformément à une technique de démodulation prédéterminée afin d'identifier les composantes du vecteur de symbole émis.

15. Récepteur selon la revendication 14, dans lequel le processeur de détection (201) comporte le traitement répété de données caractérisant l'environnement de transmission afin de générer un ensemble de m vecteurs de filtre adaptés spatialement offrant le meilleur Rapport Signal/Bruit (SNR) pour détecter les composantes du vecteur de symbole émis.

16. Récepteur selon la revendication 14, dans lequel l'ordre de détection des composantes du vecteur de symbole émis sert à maximiser le rapport signal/bruit minimum du processus de détection.

FIG. 1

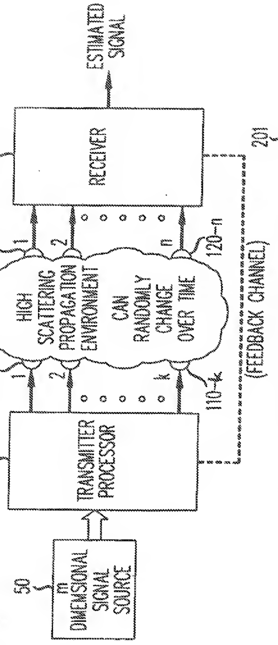


FIG. 2
200

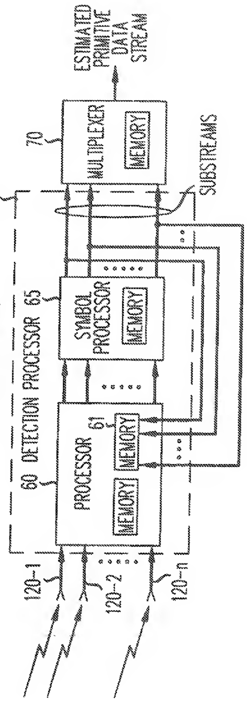


FIG. 3

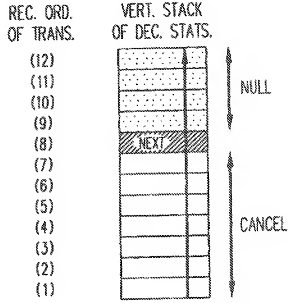


FIG. 4

FORMATION OF DECISION STATISTIC FOR $q_{(8)}(t)$

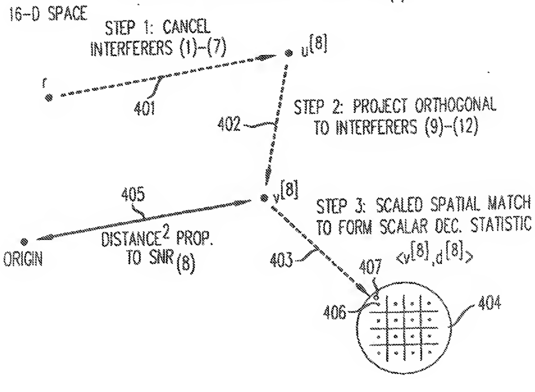


FIG. 5

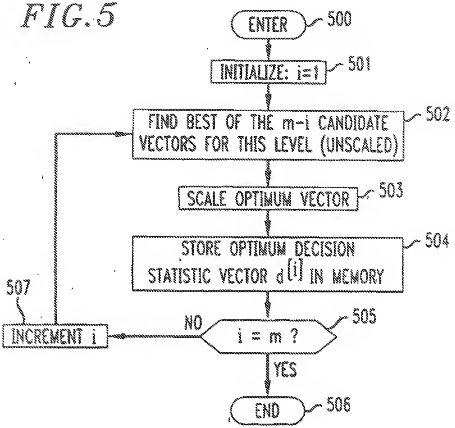

ENTER
500
INITIALIZE: i=1
501
FIND BEST OF THE m-i CANDIDATE VECTORS FOR THIS LEVEL (UNSCALED)
502
SCALE OPTIMUM VECTOR
503
STORE OPTIMUM DECISION STATISTIC VECTOR d[i] IN MEMORY
504
507
INCREMENT i
NO
i = m ?
505
YES
END
506

FIG. 7

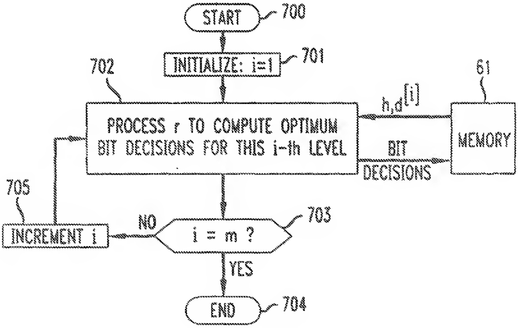
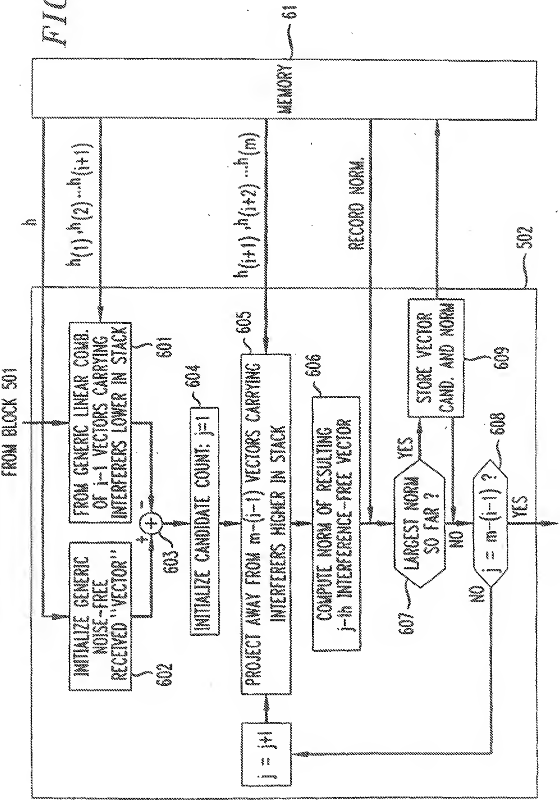

START
700
INITIALIZE: i=1
701
702
61
h,d[i]
PROCESS r TO COMPUTE OPTIMUM BIT DECISIONS FOR THIS i-th LEVEL
MEMORY
BIT DECISIONS
705
INCREMENT i
NO
i = m ?
703
YES
END
704

FIG. 6


MEMORY
61
h
$h_{(1)}, h_{(2)} \cdots h_{(i+1)}$
$h_{(i+1)}, h_{(i+2)} \cdots h_{(m)}$
RECORD NORM.
502
FROM BLOCK 501
FROM GENERIC LINEAR COMB. OF i-1 VECTORS CARRYING INTERFERERS LOWER IN STACK
601
INITIALIZE GENERIC NOISE-FREE RECEIVED "VECTOR"
602
603
INITIALIZE CANDIDATE COUNT: j=1
604
PROJECT AWAY FROM m-(i-1) VECTORS CARRYING INTERFERERS HIGHER IN STACK
605
COMPUTE NORM OF RESULTING j-th INTERFERENCE-FREE VECTOR
606
LARGEST NORM SO FAR ?
607
YES
NO
STORE VECTOR CAND. AND NORM
609
j = m-(i-1) ?
608
YES
NO
TO BLOCK 503
j = j+1

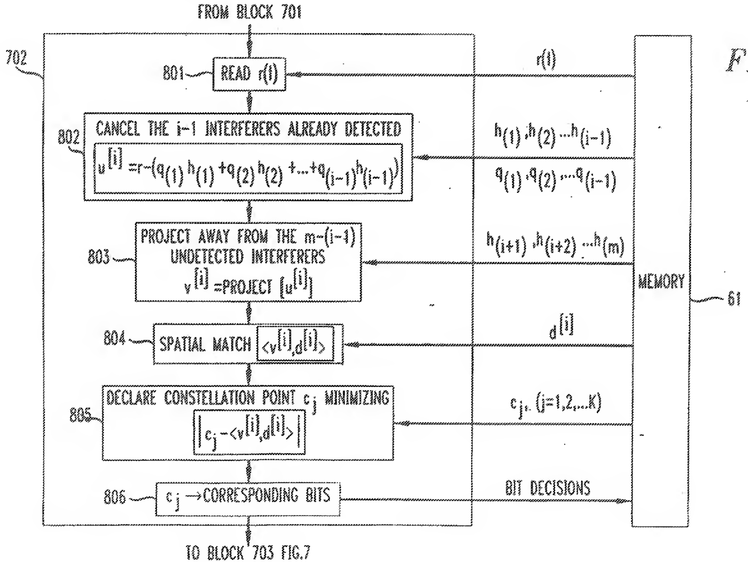

FROM BLOCK 701
702
801
READ r(l)
802
CANCEL THE i-1 INTERFERERS ALREADY DETECTED
u[i] =r-(q(1) h(1) +q(2) h(2) +...+q(i-1) h(i-1))
803
PROJECT AWAY FROM THE m-(i-1) UNDETECTED INTERFERERS
v[i] =PROJECT [u[i]]
804
SPATIAL MATCH <v[i],d[i]>
805
DECLARE CONSTELLATION POINT cj MINIMIZING
|cj-<v[i],d[i]>|
806
cj →CORRESPONDING BITS
TO BLOCK 703 FIG.7
r(l)
h(1),h(2)...h(i-1)
q(1),q(2),...q(i-1)
h(i+1),h(i+2)...h(m)
d[i]
cj, (j=1,2,...K)
BIT DECISIONS
MEMORY
61

FIG.8

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- EP 0817401 A [0003]
- EP 0905920 A [0004]